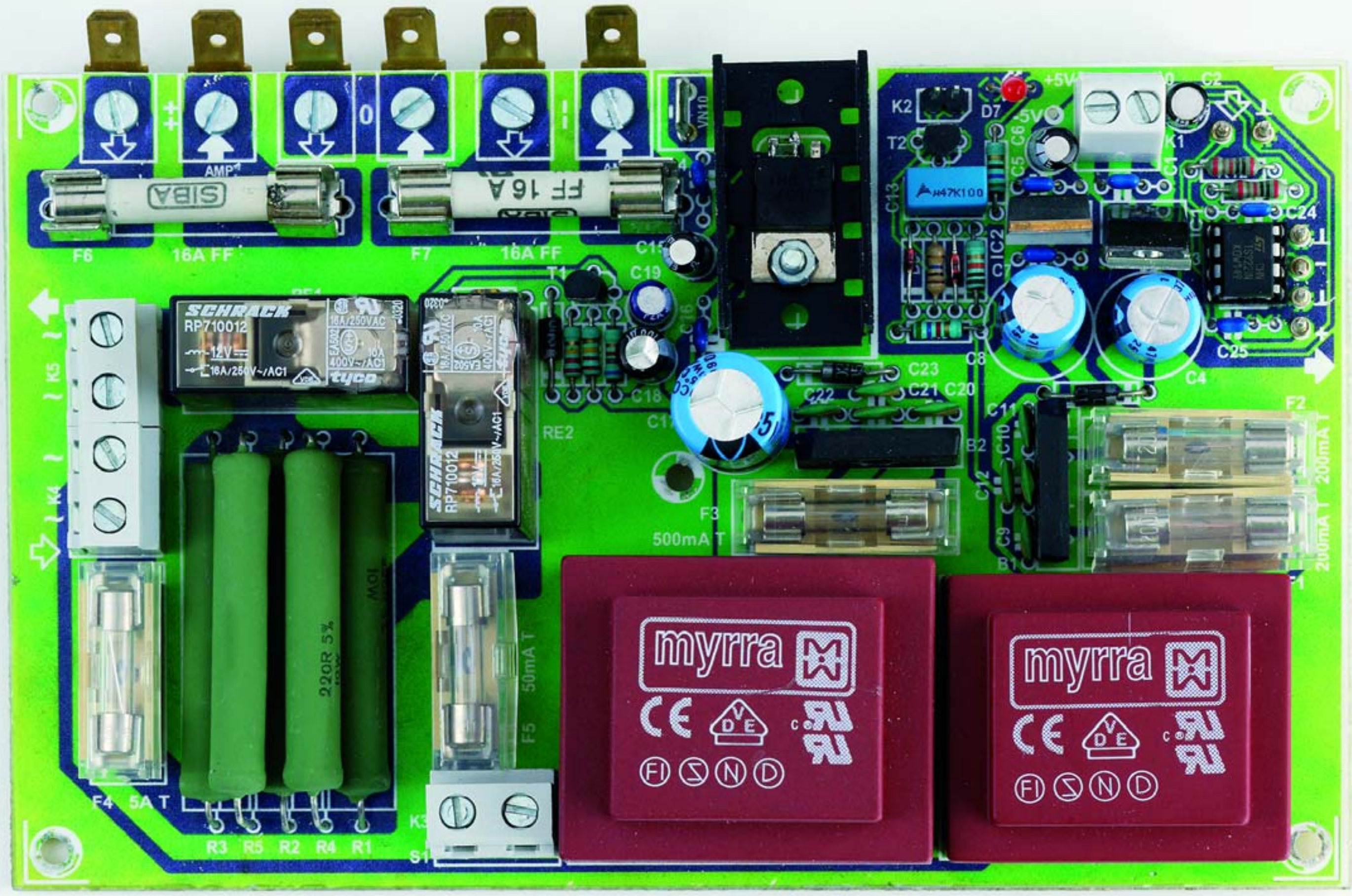
ClariTy 2x300W Class-T



Ton Giesberts

As already mentioned in the previous parts of this article, this final amp needs more than just a heavy-duty symmetrical power supply. In this final part, we examine the main power supply, the other power supplies, final assembly and alignment.

The analogue input portion of the TA3020 operates from a stabilised 5-V supply voltage. A stabilised 10-V auxiliary voltage is also needed for driving the MOSFETs. The power supply board also has a switch-on delay for the mains voltage (current limiting). An additional feature is a buffer circuit with a phase inverter, which allows the two channels to be easily operated in a bridge configuration without requiring any modifications to the amplifier board. Naturally, the required mains power indicator and mute signal are also present.

Amplifier

Part 3: power supply, assembly and alignment

Analogue power supply and mute circuit

The analogue 5-V power supply has its own transformer (TR1, 2 × 9 V). A small, discrete-component circuit for generating a well-defined mute signal is added here (see **Figure 1**). The supply voltage for this circuit is taken directly from the output of the bridge rectifier (B1), filtered by a small capacitor (C14), so the amplifier can be switched to mute mode as quickly as possible when the mains voltage drops out.

The mute circuit is the height of simplicity: after C13 has been charged, T2 has enough voltage to fully drive the optocoupler on the amplifier board. C13 is slowly charged via R11 until it reaches the level defined by voltage divider R9/R10. D2 limits the voltage at the mute output, but the ultimate value is not especially critical. When the mains voltage drops out, C13 is quickly discharged by D3. The mute signal can be connected to the amplifier board via pin header K2.

The negative supply voltage is only needed for powering the phase inverter. Standard positive and negative voltage regulators are used for the +/– 5-V supplies. The +5-V supply can be connected to the amplifier board via K1. The negative voltage is also available on a solder pin, so it is also available for user-defined applications.

Auxiliary voltage and switch-on delay

The 10-V supply for the output stage is also powered by a separate transformer (TR2). After rectification and filtering, the voltage is stabilised using a standard positive 10-V regulator. If a 10-V regulator is difficult or impossible to obtain, a 9-V type can also be used. Two different types of transformer are shown on the schematic diagram for this supply. The PCB is designed to accommodate a transformer with two separate windings (2 × 6 V) or one with a single winding (1 × 12 V). In either case, a 12-V ac voltage is thus made available. Just as with the analogue supply, the filter is placed after an extra diode, rather than directly following the bridge rectifier.

The voltage provided by rectifier B2 is used to power the relays of the mains switch-on delay circuit. This voltage also has minimal filtering (C19). This causes the relays to disengage as quickly as possible when the mains voltage drops out.

The switch-on delay circuit consists of two relays. The first relay (RE1) switches on power to the amplifier via a set of high-power resistors in order to limit the magnetising current of the transformer and the charging current for the electrolytic capacitors of the main power supply. These high-power resistors consist of five 10-W, 220-Ω resistors connected in parallel. Two of them are mounted above the other three, separated by a certain amount. The peak load capacity must be taken into account in dimensioning these resistors. The transient power dissipation is around 1200 W, and the absolute peak dissipation is actually more than 2 kW!

The second relay (RE2) shorts out the resistors and connects the main power supply transformer (a 1000-VA type in our prototype) directly to the main voltage. This allows the amplifier to manage with a relatively small mains switch (6-A rating). With the delay circuit, the effective value of the switch-on current does not exceed 5.2 A.

The drive circuit for the switch-on delay is a standard design. Voltage divider R6/R7/R8 ensures that the voltage at the base of T1 is not high enough for it to conduct enough current to energise RE2 until the supply voltage has reached two thirds of its nominal value. The time required for this voltage to be reached is delayed by the charging time of C20. The value of C20 can be kept to a minimum by using equal values for R6 and R7 to set the delay time. When the mains voltage drops out, D5 causes C20 to be rapidly discharged. With this arrangement, the delay time remains as nearly as possible constant if the supply is switched off and then quickly switched on again.

The required mains power indication is provided by LED D7. It must therefore be clearly visible on the front of the amplifier.

Main power supply

The compactness of the amplifier is offset by the sheer mass of the power supply. Of course, we could have also developed a switch-mode power supply, but it would have to be a supply that could deliver a good 40 A at a bit less than +/– 60 V. That would be a challenge, to put it mildly. It should thus be clear why we choose to use a conventional design.

In consideration of the current levels involved here, we selected a heavy-duty rectifier that can handle a rated current of 46 A and a peak current of 90 A. For the electrolytic capacitors in the power supply, we selected types that can handle strong ripple currents. Normal power-supply electrolytics are not intended to be used in such severe applications. From the BCcomponents 2222 154 line, we selected a capacitor that can handle ripple currents of around 11 A at 10 kHz (or 20 A at 100 Hz) and has low values of self-inductance and ESR (a tall electrolytic capacitor with a small diameter). A long service live is ensured by connecting four capacitors in parallel for each half of the power supply. Here we can give you a small tip: if you order ten capacitors in a single lot from Farnell, it will cost you less than buying eight of them at the single-quantity price.

If you think the power supply is perhaps somewhat over-designed with the

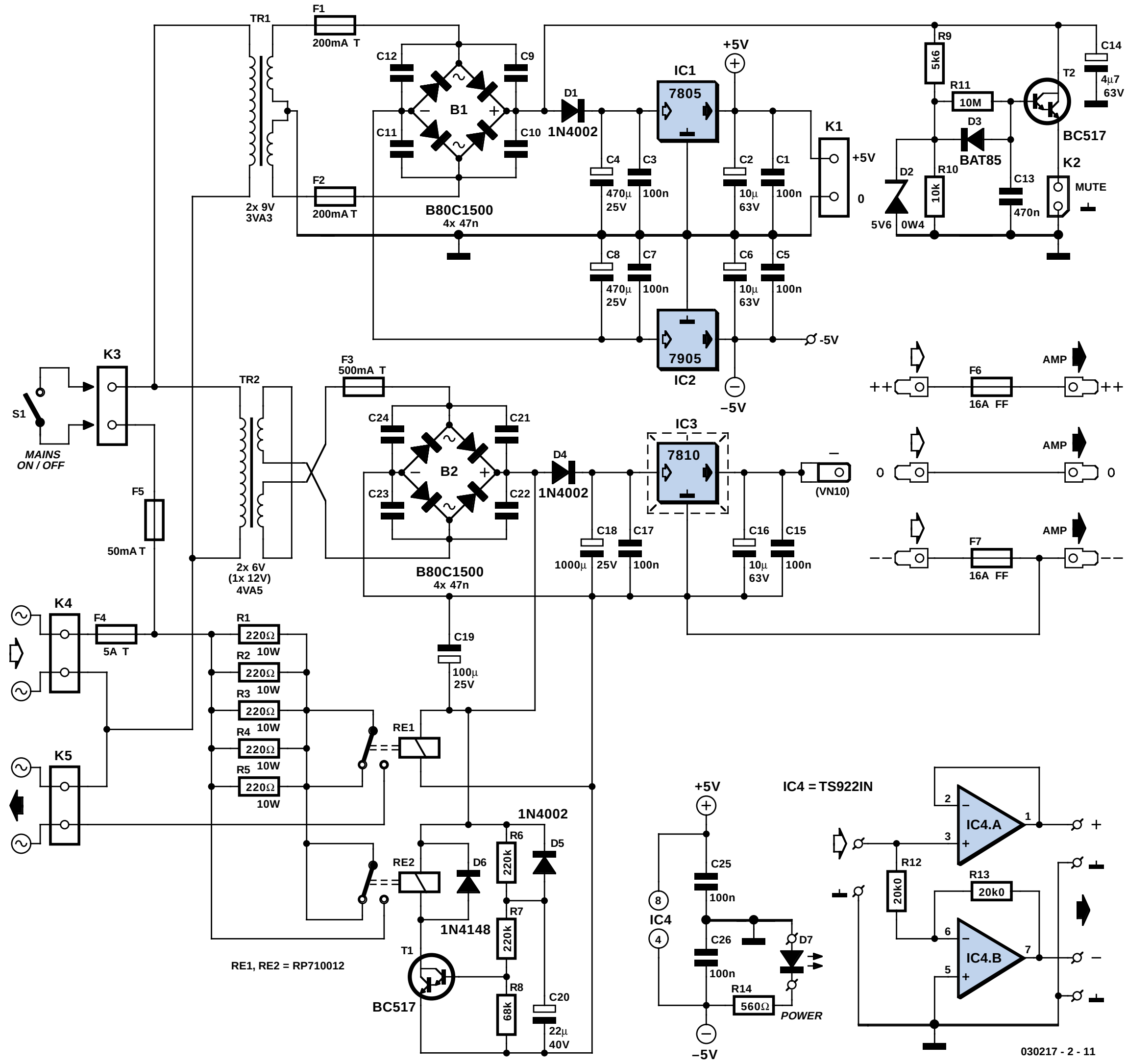


Figure 1. Besides the auxiliary supply voltages, the power supply board provides the switch-on delay, the mute signal and a phase inverter for bridge-mode operation.

COMPONENTS LIST

power supply board

Resistors:
R1-R5 = 220Ω 10W (e.g. AC10 BCcomponents)
R6,R7 = 220kΩ
R8 = 68kΩ
R9 = 5kΩ6
R10 = 10kΩ
R11 = 10MΩ
R12,R13 = 20kΩ0 1%
R14 = 560Ω

Capacitors:
C1,C3,C5,C7,C15,C17,C25,C26 = 100nF ceramic
C2,C6,C16 = 10µF 63V radial
C4,C8 = 470µF 25V radial
C9-C12,C21-C24 = 47nF ceramic
C13 = 470nF
C14 = 4µF7 63V radial
C18 = 1000µF 25V radial
C19 = 100µF 25V radial
C20 = 22µF 40V radial

Semiconductors:
D1,D4,D5 = 1N4002
D2 = zener diode 5.6V 0.4W
D3 = BAT85
D6 = 1N4148
D7 = LED, red, low-current
T1,T2 = BC517
IC1 = 7805
IC2 = 7905
IC3 = 7810
IC4 = TS922IN ST (Farnell # 332-6275)

Miscellaneous:
B1,B2 = B80C1500, straight case (– ~ + ~) (80V piv, 1.5A)
K1 = 2-way PCB terminal block, lead pitch 5mm
K2 = 2-way pinheader
K3,K4,K5 = 2-way PCB terminal block, lead pitch 7.5 mm
F1,F2 = fuse, 200mA/T (time lag) with PCB mount holder
F3 = fuse, 500mA/T (time lag) with PCB mount holder
F4 = fuse, 5A/T (time lag) with PCB mount holder
F5 = fuse, 50mA/T (time lag) with PCB mount holder
F6,F7 = fuse, 16A/FF (very fast), 6.35x32 mm (Farnell # 534-699 with fuse clips # 230-480)
RE1,RE2 = RP710012 16A/12V/270Ω (Schrack, Farnell # 388-312)
TR1 = mains transformer, 2 x 9V/3.3VA (e.g., Myrra 44200, 2 x 1VA6)
TR2 = mains transformer, 2 x 6V (or 1 x 12V)/4VA5 (e.g., Myrra 44235, 2 x 2VA5)
1 x spade terminal, PCB mount, 2-way, straight
6 x spade terminal, PCB mount, 3mm screw/bolt mounting
Heat-sink 15 K/W for IC3 (ICK35SA Fischer)
S1 = mains on/off switch rated for 6 A

main supply

Mains transformer 1000VA, 2 x 42V/11.9 A (e.g., Amplimo/Jaytee Z8022)
Bridge rectifier 140V/50A (e.g. Diotec Semiconductor KBPC 5002FP, Farnell # 393-5292)
8 electrolytic capacitors, 63V/15,000µF (e.g, BCcomponents # 2222 154 18153, Farnell # 248-022)
4 mounting clamps for 35-mm diameter electrolytics (Farnell # 306-526)
IEC mains appliance socket, chassis mount
PCB, order code 030217-2

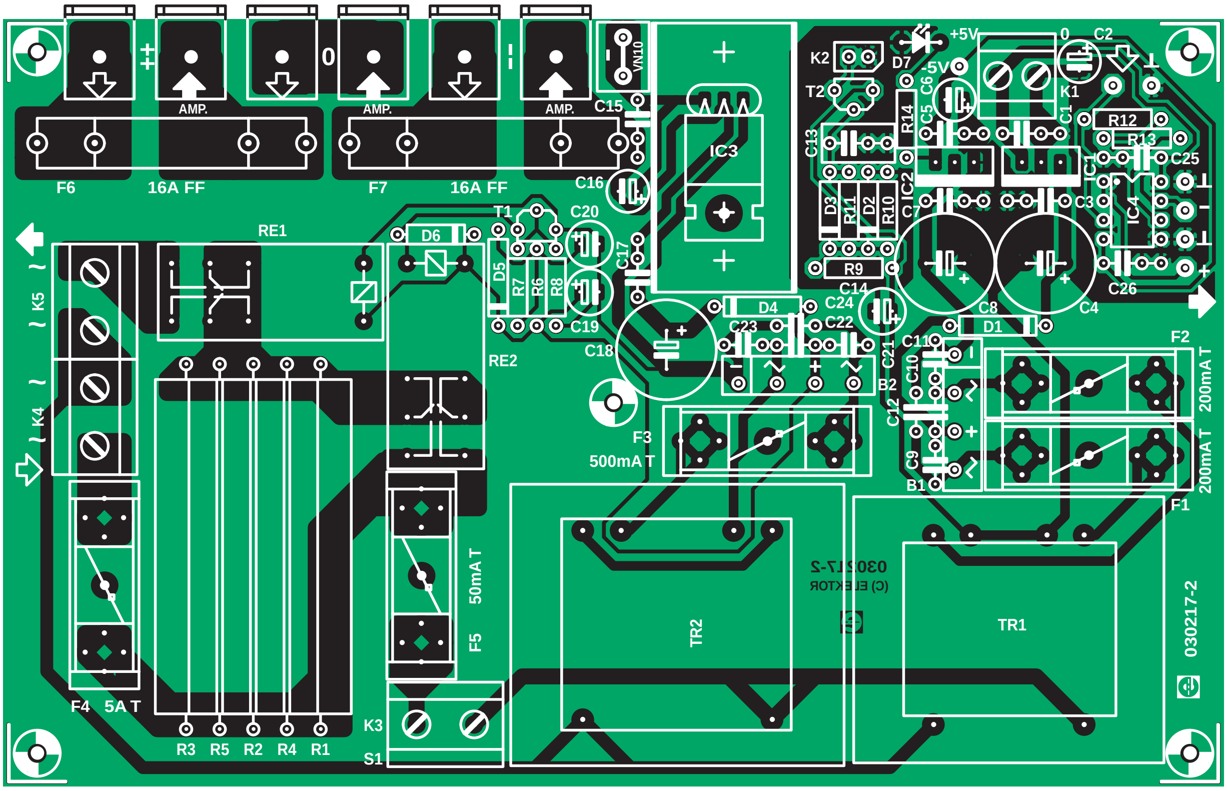


Figure 2. The power supply board also has room for several fuses, which provide good protection for the amplifier.

specified component values, we wouldn't immediately disagree. However, you should bear in mind that at 2 × 200 W sine-wave power, the output voltage of this supply already drops by 5 V!

Protection

The mains voltage is routed to the power supply board via K4. The primary fuse for the main transformer (F4) is also fitted here, so it isn't necessary to use a mains connector with a built-in fuse. The mains voltage for the auxiliary voltages is tapped off after the fuse for the main transformer. If the primary fuse blows, power will also be removed from the rest of the amplifier. In the opposite case, a similar situation exists. If the fuse for TR1 and TR2 blows, the supply voltage for the mains switch-on delay circuit will drop out, and power will be removed from the entire amplifier. A situation in which only part of the amplifier is without power can occur of F1 and/or F2 blows. In this case, at most the +5 V supply voltage will be lost, and there will no longer be any signal. That will not have any further detrimental effects; the most that can happen is that a small 'pop' will be heard from the speakers.

For additional safety, the main supply voltage for the final amp is protected using two 16-A FF fuses in 32-mm cases. This ensures that the voltage decays as quickly as possible in case of a short circuit, rather than requiring the power supply capacitors to first be discharged. These fuses are also fitted on the power supply board, and they are connected between the large power supply capacitors and the amplifier board using screw-mounted flat connectors (car connectors). The advantage of using separate fuse holders is that the PCB-mount fuse clips used here can handle a continuous current of no less than 15 A (with adequate copper area on the circuit board). Most PCB fuse holders are only rated at 5 A continuous current.

Assembly

For our prototype, we chose the 'not so quick-and-dirty' method and fabricated our own enclosure from a sheet of aluminium. This results in an unconventional design, whose shape and proportions are determined by the dimensions of the heat sink, toroidal transformer, power-supply capacitors and power supply board (**Figure 2**). The heat sink forms the front of the unit. The mains entry, input sockets and speaker connectors are fitted at the rear. Of course, you are free to package everything into another type of (standard) enclosure.

In our design, we tried to keep the power supply connections as short as possible, and we fitted the power supply board above the large toroidal transformer. The four fastening holes for this board are far enough apart to allow it to be secured to the base with ample clearance from the transformer. The two rows of four electrolytic capacitors each are placed next to each other in a single group. Their terminals are connected together using small 2-mm aluminium plates. Be sure to provide adequate separation between the plates for the +, 0 and – polarities. We recommend fitting screw-mounted flat connectors to the plates, to simplify wiring and maintenance.

The capacitors can be adequately secured using four mounting clamps. Where necessary, one mounting tab must be broken off of each clamp.

The wiring diagram is shown in **Figure 3**, which also shows the filter boards. These still have to be described.

The two centre taps of the transformer (neutral/ground) are connected to one

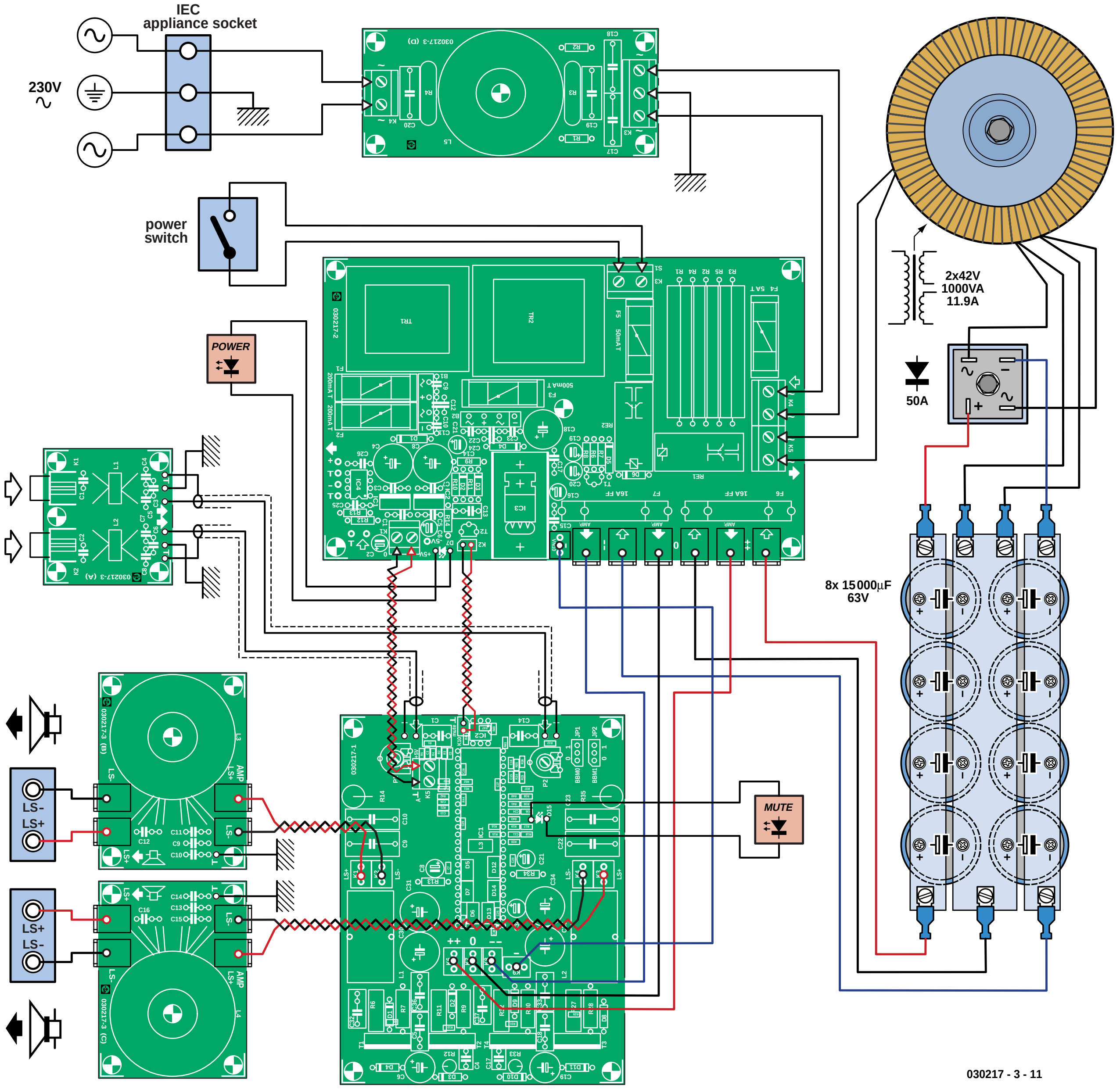


Figure 3. The wiring diagram also shows the filters. Be sure to keep the connections as short as possible!

side of the common ground plate for the electrolytic capacitors, between the plus and minus leads from the bridge rectifier. In our design, the bridge rectifier is fitted to the side panel, which provides it with an adequate cooling surface.

On the opposite side of the electrolytic capacitors, the three power supply terminals (including neutral) are connected to the terminals on the power supply board marked with ‘input’ arrows. The four terminals for the supply voltages are thus available on the power supply board. The path to the amplifier board must be as short as possible. This also applies to the 10-V auxiliary voltage!

For the main supply voltage, stranded wire with a cross section of at least 4 mm^2 must be used. The mute signal for the amplifier is generated on the power supply board. It is connected to the amplifier board using a twisted pair of small-diameter stranded wires.

The analogue supply voltage is connected to the amplifier board using a twisted pair of stranded wires (1.5 mm^2).

The mains voltage output from the power supply board is connected directly to the large toroidal transformer.

There is room to fit a small fan on the rear panel for internal cooling, if so desired. Try to route the cables for the input signals as far away from the transformers as possible. The loudspeaker leads must be wired as a twisted pair for each channel to counter the effects of interference fields.

Alignment

The only alignment that is required is to adjust the dc offsets of the outputs, which can be done after the amplifier is assembled but should preferably be done during testing before final assembly. Naturally, the dc offset voltages must be set to zero. The offsets must be adjusted (using P1 and P2 on the amplifier board) with the amplifier

Two channels in bridge mode

If a stereo amplifier is to be used in bridge mode, the two channels must be supplied with signals having the same amplitude and opposite phases. To avoid having to change any connections or components on the amplifier board, a simple buffer circuit is provided on the power supply board. IC4a is wired as a voltage follower, and IC4b is configured as an inverting amplifier. This means that besides two decoupling capacitors for the supply voltages, only two opamps and two resistors are necessary. Since balanced supply voltages are used, no decoupling capacitors are required for any dc offsets that may be present at the inputs or outputs. Due to the simple design, small offset voltages may be present at the outputs, but the final amplifier is ac coupled and thus totally immune to such offsets.

For proper operation and low distortion, careful attention must be given to the polarity of the loudspeaker filter connections when the final amplifier board is operated in bridge mode. In this case, the amplifier is wired exactly the same as for stereo operation. Naturally, it's only necessary to build the input filter for a single channel. The output from the input filter goes to the buffer circuit on the power supply board (IC4). Two signals go from the buffer to the inputs on the final amplifier board. It goes without saying that these connections must be made using good-quality, screened audio cable. The two LS+ outputs from the loudspeaker filters form the speaker terminals of the bridge amplifier. As the return currents from the filters would have nowhere to go if the LS– outputs were left open, the two LS– outputs must be connected together. If the amplifier is used in bridge mode, it is essential to ensure that the amplifier outputs are not accidentally shorted together (due to incorrect wiring, for example).

switched on and operating in normal mode (not muted), with its rated load but without any drive signal.

In the mute mode without any load, the amplifier has an output impedance of approximately 10 kΩ. In this situation, there will be a small voltage on the output, but this does not have to be adjusted.

Besides adjusting the offset, the only other alignment is the dead-time setting for the MOSFET drive circuitry. This is determined by the positions of jumpers JP1 and JP2 (or BBM0 and BBM1). Set the dead time to 80 ns by setting JP1 to '1' and JP2 to '0'. There's no point in experimenting with other values. Using a larger value causes increased distortion, and using a smaller value causes short-circuit currents to flow through the MOSFETs, which can be fatal for them.

Table 1.
Dead-time jumper settings

JP2 BBM1	JP BBM0	t ns
0	0	120
0	1	80
1	0	40
1	1	0

All possible settings are listed in **Table 1**. The component overlay on the amplifier board also clearly indicates the proper positions of the jumpers.

Final remarks

There are a couple of things we still have to tell you. The first is that the amplifier can be used bridge configuration, as explained in the 'Two channels in bridge mode' text box. Another essential aspect is the measured performance, which is also described in a separate box. The measurements were made using the complete amplifier, which means including the filters. Unfortunately, there is not enough room to describe the filter circuits in this article. For the time being, you can also use the amplifier without the filters, but we strongly recommend including them in the overall system.

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Measured performance

The results described here were measured using a 1000-VA power supply transformer with two windings rated at 42 V / 11.9 A, together with two sets of four 15,000-µF / 63-V electrolytic capacitors. The measurements were made using the fully assembled prototype. An additional 40-kHz passive second-order Butterworth filter with an air-core inductor was used for measuring intermodulation distortion and dynamic IM distortion.

Input sensitivity (2 × 300 W / 4 Ω)		1.13 V (THD+N = 1.5 %)
Input impedance		18.9 kΩ
Sine-wave power (1 kHz / THD+N = 0.1 % / B = 22 Hz – 22 kHz)		2 × 266 W / 4 Ω
		2 × 156 W / 8 Ω
Sine-wave power (1 kHz / THD+N = 1 % / B = 22 Hz – 22 kHz)		2 × 291 W / 4 Ω
		2 × 167 W / 8 Ω
Sine-wave power in bridge mode (1 kHz / THD+N = 1 % / B = 22 Hz – 22 kHz)		600 W / 8 Ω
		735 W / 6 Ω
Bandwidth (via 9th-order elliptic filter with B = 180 kHz)		2.4 Hz – 98 kHz (4 Ω / 1 W)
		2.4 Hz – 122 kHz (8 Ω / 1 W)
SNR (B = 22 Hz – 22 kHz)		> 68 dB (referred to 1 W / 4 Ω)
		> 71 dB (referred to 1 W / 8 Ω)
Harmonic distortion (1 kHz) (B = 22 Hz – 22 kHz)	2 × 1 W / 4 Ω	< 0.04 %
	2 × 1 W / 8 Ω	< 0.03 %
	2 × 200 W / 4 Ω	< 0.02 %

	2 × 100 W / 8 Ω	< 0.02 %
2nd harmonic alone	2 × 1 W / 4 Ω	< 0.01 % (THD+N = 0.037 %)
	2 × 10 W / 4 Ω	< 0.02 % (THD+N = 0.023 %)
	2 × 25 W / 4 Ω	< 0.025 % (THD+N = 0.026 %)
	2 × 100 W / 4 Ω	< 0.013 % (THD+N = 0.017 %)
2nd and 3rd harmonics	2 × 200 W / 4 Ω	< 0.015 % (THD+N = 0.018 %)
Intermodulation distortion	1 W / 4 Ω	< 0.1 %
(50 Hz : 7 kHz = 4 : 1)	1 W / 8 Ω	< 0.1 %
	300 W / 4 Ω	< 0.06 %
	150 W / 8 Ω	< 0.0 %
Dynamic IM distortion	1 W / 4 Ω	< 0.035 %
(3.15-kHz square wave with 15-kHz sine wave)	1 W / 8 Ω	< 0.03 %
	300 W / 4 Ω	< 0.025 %
	150 W / 8 Ω	< 0.01 %
Damping (8 Ω / 1 kHz)	> 140	
Channel separation	200 W / 4 Ω / 1 kHz	> 94 dB
	100 W / 8 Ω / 1 kHz	> 100 dB
	200 W / 4 Ω / 20 kHz	> 77 dB
	100 W / 8 Ω / 20 kHz	> 77 dB

Besides these ‘clinical’ measurement figures, we have also recorded several curves. They probably give a better picture of the character of the amplifier, although ultimately only a listening test can provide a reliable conclusion.

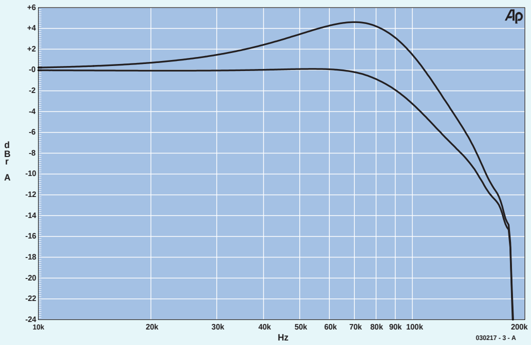
Figure A shows the effect of the output filter (on the final amplifier board) on the amplitude response. The upper curve is measured with an 8-Ω load and shows a rise of +0.7 dB at 20 kHz and +4.6 dB at 70 kHz. Comparison with the measurement for 4 Ω clearly shows that the filer is optimised for 4 Ω, for which it exhibits an exemplary straight-line characteristic. The sudden sharp drop-off in the curve at the end of the measured range is due to the ninth-order elliptic filter used for this measurement.

Figure B shows THD+N versus output level for a bandwidth of 22 Hz to 22 kHz with a 4-Ω load. The rise in the middle of the curve (around 20 W) is partly due to the influence of the other channel (additional noise). All in all, the distortion over the entire output power range up to 200 W can be considered to be nicely constant. At levels above 200 W, distortion increases due to the additional modulation applied to the amplifier output. Here the amplifier exhibits behaviour that resembles soft clipping, but true limiting only occurs at around 300 W into 4 Ω. This is also strongly dependent on the strength of the power supply. An additional second-order filter was used for this measurement to slightly smooth the curve. Without this filter, the distortion is somewhat lower (e.g. 1 % at 291 W).

Figure C shows the maximum output power for loads of 2 × 4 Ω and 2 × 8 Ω. For 4 Ω, the distortion was held constant at 1 %, and for 8 Ω it was held constant at 0.5 %. Both measurements were made over a bandwidth of 22 Hz to 22 kHz. The power appears to increase starting at around 6–8 kHz, but this is naturally due to the fact that the filter suppresses harmonics above these frequencies. The curves should be drawn with a slightly dropping line starting at 5 kHz. The maximum power is slightly greater at low frequencies than at high frequencies. At 50 Hz it is approximately 163 W into 8 Ω or 306 W into 4 Ω, while at 1 kHz it is approximately 160 W into 8 Ω or 291 W into 4 Ω. The effect is thus slightly greater at lower impedance, but this is not perceptible in actual practice.

Finally, **Figure D** shows the frequency spectrum of a 1-kHz signal for 1 W into 4 Ω.. This was measured using an additional 40-kHz second-order Butterworth filter in order to prevent HF noise in the A/D converter from affecting the FFT analysis. The second harmonic thus actually lies slightly below 80 dB (< 0.01 % distortion). No power-supply ripple or other irregularities are visible here. Despite the fact that a portion of the pulse-width modulation can be seen with 1 W at the output of the amplifier, the spectrum within the audio band can be considered to be quite clean. The small bump at 50 kHz does not require any comment.

A



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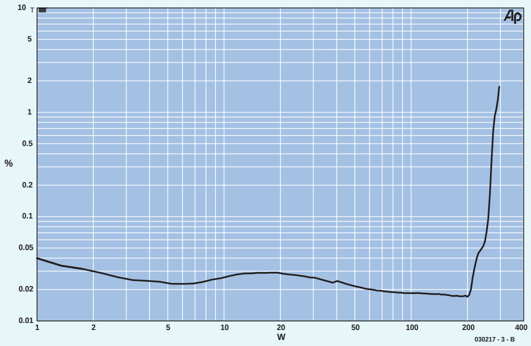

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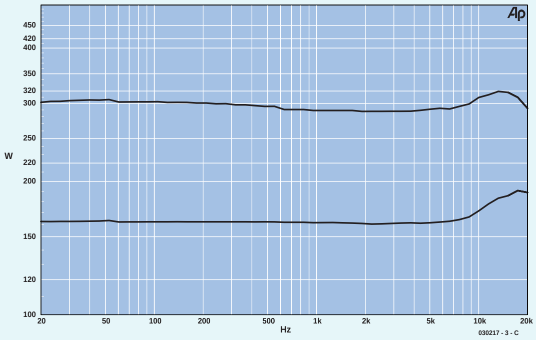

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